Large Scale Interactive Data Visualization for Undersea Warfare Applications

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ABSTRACT

Today, the US Navy's submarine fleet is equipped with a multitude of advanced, highly capable acoustic sensors and systems that are utilized in many aspects of tactical, navigational, and operational Command and Control (C2). These modern sonar systems collect, process, store, disseminate, and display sensor data. Rapid advances in processing techniques, computing power, and sensor technology present a new challenge – sonar operators require extensive training and experience in order to deal with an enormous amount of acoustic data using 2D display and interaction tools, which have remained nearly unchanged in the past 25 years. Fraunhofer CRCG and the Naval Undersea Warfare Center present a highly interactive Large Scale Visualization Environment (LSVE) for performing the essential tasks of detection and classification of sonar contacts. Our prototype application employs a semi-immersive 3D display system, multiple and mixed modalities of interaction and feedback, and state-of-the-art volumetric visualization techniques. An operator can use the LSVE to rapidly detect a contact in a low signal to noise environment and perform the tasks of detection, tracking, and classification of contacts.

Index Terms – Data Visualization, Sonar, Interactive Data Analysis.

INTRODUCTION

Submarine sonar system technology has benefited in recent years primarily from accelerated developments in digital signal processing, computational power, and advances in sensors. Today's most capable undersea platforms deploy several different acoustic sensor arrays both, hull-mounted and towed. Each sensor suite is specifically designed for a particular mission, creating a massive amount of sensor data to be analyzed by the sonar operators. Even though these sonar arrays and processing systems are state-of-the-art, the presentation of acoustic data to the operator onboard these platforms has not appreciably changed in the last 35 years.

The analysis of relatively low-level sensor data by an operator is unique today to sonar Operators must search and evaluate acoustic energy across many frequency bands, apertures, arrays and directions,

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and make decisions on the presence or absence of contacts of interest, largely unassisted by automation. The sonar operator is challenged by an enormous data overload problem, coupled with antiquated, non-intuitive display technology with restricted interaction and limited tools to accomplish the vital tasks of detection, tracking, and classification of contacts.

To maximize performance under these conditions, the conduct of undersea warfare requires the highest degree of information extraction and exploitation from a myriad of onboard acoustic sensors and processing systems. A new technology and human systems approach is needed in order to focus high-performance computing, display, and human/machine interaction technologies on the problems and tasks faced by human operators and decision makers.

INTERACTIVE APPLICATIONS FOR SONAR DATA PROCESSING

In collaboration with the Naval Undersea Warfare Center (NUWC) in Newport, Rhode Island, the Fraunhofer Center for Research in Computer Graphics (CRCG), Inc., has taken the approach of developing intuitive, highly interactive analysis tools to increase the performance of the sonar operator.

Interactive Data Exploration

At the most basic level, the challenge from an interaction point of view is to provide access and manipulation tools to find correlations that are hidden in the vast amount of data available to the user.

EZ-Grams – Exploiting Harmonic Relationships

By focusing on perceptual information cues, NUWC and Fraunhofer CRCG have developed interactive, intuitive tools and techniques by which the operator can rapidly extract pertinent information from the raw data within a specific task domain. Collectively, these display tools are represented as a new class of aids called *EZ-grams*, which help an operator transform raw sensor data into useful information [Barton, Rowland et al. 2000]. An *EZ-Gram* embodies a collection of pertinent sensor data that represents the hypothesis that a contact is of interest. *EZ-Grams* allow operators to rapidly test hypotheses, search for corroborating data, and build confidence in the solution.

One such EZ-Gram is the *harmonogram*, which is based upon an hypothesis that energy of interest exists in some or all of the harmonics associated with a given or selected frequency band, or “bin.” The frequency bins of the harmonogram are superimposed to enhance the dynamic representation of Doppler, while reducing non-correlated data in the display. Furthermore, the harmonogram displays time-record data through animation, allowing the user to “replay” local history and view target or contact motion, which can provide valuable insight into signal dynamics. Subtle effects not observed in single image data presentations are potentially quite obvious when animated.

Figure 1 shows a typical time-frequency or “waterfall” representation of acoustic sensor data presented to a sonar operator today, in which data correlations are difficult to discern. In most cases, each gram has time on the vertical axis, and either bearing or frequency along the horizontal. Signal intensity is monochrome and subsampled down to only 8 levels, i.e. 3 bit resolution presentation. These displays are the primary workplace for the sonar operators.

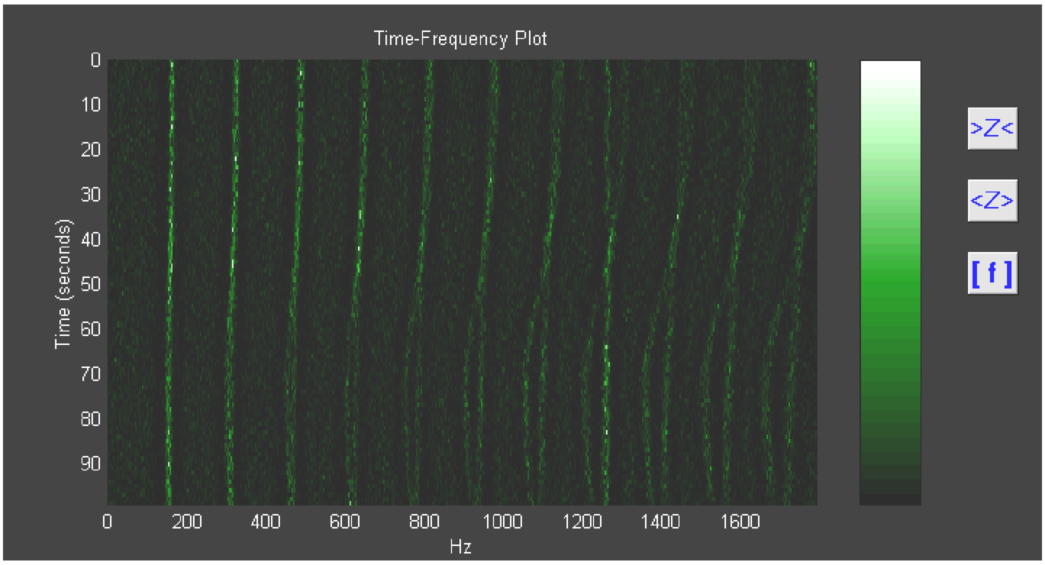

Figure 1: Typical Time-History Spectrogram Sonar Display.

Figure 2 shows a harmonogram in which a selected hypothesis is clearly shown to be valid, because it is displayed as a harmonically related frequency-frequency plot, with time history presented to the user as an animated sequence. Note that only the data already available in the waterfall is portrayed in the harmonogram, but the data is filtered to the hypothesis of interest, and displayed so that the information cues that the operator is seeking are distinctly presented. NUWC is currently developing several examples of EZ-Gram display tools for transition into current and future US Naval submarine sonar display systems.

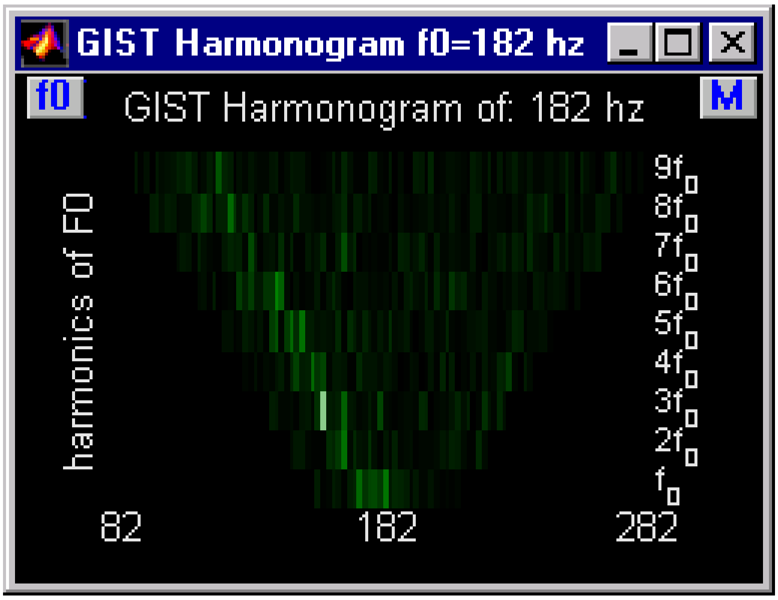

Figure 2: Harmonogram Representation.

Large Scale Visualization Environment

Fraunhofer CRCG and NUWC have used a two-stage approach in the development of an intuitive, highly interactive, Large Scale Visualization Environment (LSVE) that will enable human talents, experience,

and intuition to leverage and direct high-performance computing resources [Encarnação, Barton et al. 2000]. The LSVE consists of two main components, "search&detect" and "analyze&classify" which will be discussed below. The LSVE has been implemented on a "virtual table" display device as seen in Figure 3. The rear-projection display surface can be oriented at any angle from horizontal to nearly vertical.

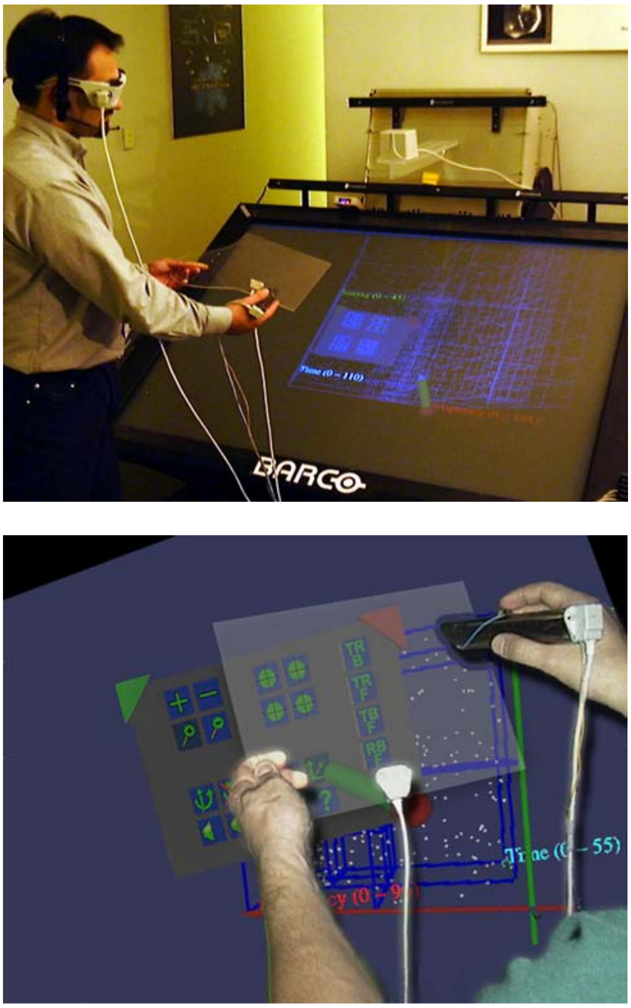

Figure 3: System Setup (above). The Two-Handed Input Device – Pen and Pad – for the Virtual Table (below).

Transparent pen and pad props made of Plexiglas have been created to display stereoscopic 3D graphics that the user perceives as coincident with the physical position of the devices [Schmalstieg, Encarnação et al. 1999]. The transparent non-reflecting surface of the pad virtually disappears when the table graphics are switched on. The user then sees computer-generated images while the physical properties of pen and pad are retained. In particular, pen and pad allow tactile feedback and users intuitively understand and can easily exploit the relative position and orientation of pen, pad, and table surface.

Objects can be aligned with the surface of the pad, and also appear floating above or below the pad. The pad essentially becomes a hand-held palette that may carry all kinds of 2D and 3D user-interface elements (e. g., buttons, sliders, dials) as well as three-dimensional objects [Encarnação, Schmalstieg et al. 2000]. The pen is equipped with a single button that triggers various actions depending on the context in which it is used.

Data Management

The data sets examined in this effort were based on a Spatial Vernier (range focused) simulation of the sonar space. They consisted of one broadband data set and four bands of narrowband data. The broadband dataset is a four-dimensional dataset consisting of the dimensions *time*, *range*, *beam* and *power*. The time dimension consists of 7000 uniformly sampled bins. The beam dimension has 360 bins, each equivalent to an angular degree. The range bins consist of a eight focus distances between 2500.0 and 12000.0 yards. Therefore a signal, if it exists, will be evident in all of these ranges but focused in one. The narrow band datasets were derived from an identical simulation to the broadband data set. The difference is the narrowband data provides information on the frequency of the signal. The narrowband data set is therefore five-dimensional and is broken into four bands of frequency (A-D) between 6.0 and 450.0 Hz, which also use a different number of beams (between 45 and 360). The number of frequency bins in each dataset is 191.

Search & Detect Component

The LSVE first component (“search&detect”) aims at providing advanced visualization and human/machine interface techniques to enable sonar operators to quickly and confidently detect and classify contacts in low signal-to-noise dataspaces. This can be thought of as a problem of searching for subtle contact indicators in a very large and multidimensional dataspace. The goal is to enable the operator to focus computational resources on the volumes of interest, providing rapid initial detection.

The dataspace is represented as a set of 4D volumes, that is, 3D volumes that are dynamically updated during the time course of an operation. Multi-sensory visualization techniques are employed to indicate volumes of interest, which may contain a contact or contacts.

The operator is initially presented with a coarse visualization of potential areas of interest. This visualization employs a low-resolution visual presentation for fast searches over the data space assisting the user with the decision on where to focus attention. The visual presentation of the dataset appears subdivided in regions with a cubic shape or ‘cells’. The smaller a cell is subdivided (more resolution) the more interesting that volume is to be explored, according to the chosen analysis algorithm. Within each cell a cloud of points is displayed representing information about the signal intensity within that region. The number of points as well as the color intensity is proportional with the signal intensity. Dense white clouds represent higher signal above threshold than sparse dull color clouds.

For the exploration of the data set, numerous interaction techniques are supported, based on the transparent interaction props (pen and pad) described earlier. Voice input is also supported.

Analyze & Classify Component

In the second LSVE component (“analyze&classify”), we utilize a highly interactive 3D representation of the tactical environment. Once an area of interest has been designated in the initial search phase, the visualization coverts to a volumetric display of the multidimensional raw data of the corresponding passive narrowband sensor information. Employing visual and auditory cues, the operator can then interact with and interrogate this data cloud. Lastly, we provide aids to display non-spatial qualitative relationships in this data set, in an attempt to capitalize on inherent human pattern recognition capabilities.

At any point in time, an area of interest can be selected and then further investigated. In analyze&classify the visualization switches to the raw data view (Figure 4) of the corresponding passive narrow-band sensor information. The operator can further apply many interaction and manipulation techniques for volume data, most of which have been successfully applied in the past to the area of medical visualization. These include defining oblique and axis-parallel cutting planes to detect tracks, maximum intensity projection to enhance the contrast, and adjusting the intensity lookup table for certain known thresholds.

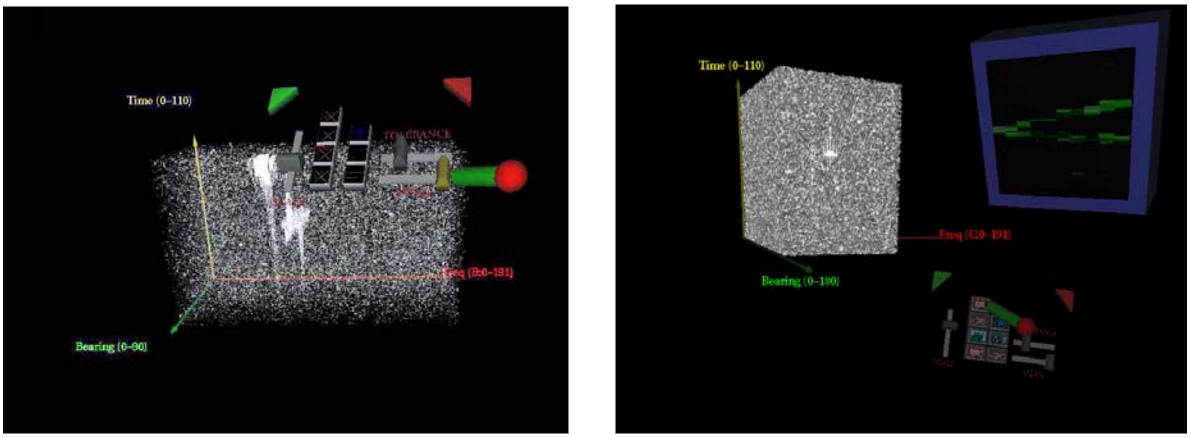

Figure 4: ‘Analyze&Classify’ Visualization: Detection of multiple threats through modification of the volumes lookup table (left) and employing an additional harmonogram (right).

In the real world we analyze objects by grabbing, rotating and bringing them closer to our eyes to get more details about interesting parts. We provide the same abilities in LSVE with our interaction tools.

While no formal evaluations have been conducted, users, including active or retired Naval personnel with USW experience, were impressed by the LSVE.

DECISION-CENTERED VISUALIZATION

Often under high-stress and workload in high-risk situations, the SONAR/Control team must rapidly achieve and maintain situation awareness – they must understand the tactical situation within the sensor performance envelope. In such situations, operators and decision makers do not have the luxury of time either to interactively specify an information presentation, or describe to a human operator what to display and how to display it.

Current work in the visualization community supports highly interactive and often immersive presentations in a variety of applications. While extensive interactive viewing and data selection is supported, current visualization systems, for the most part, only maintain information about *pixels* and *polygons*. They do *not* represent and use meta-knowledge about the data and information that is being displayed, and thus have no capacity for actively *supporting* the user by:

- presenting information known to be critical for task performance,
- alerting the user to missing data, and
- highlighting information crucial to sound decision making.

A new technology and systems approach is needed which will provide the SONAR/Control team with interactive information visualizations that merge decision support with situational awareness. An important approach to this problem is to embed in the visualization system knowledge of the application domain, the key concepts and operations, its missions, tasks, and decisions.

Fraunhofer CRCG has developed a new technology called Decision-Centered Visualization (DCV), which can provide decision makers with interactive information visualizations that merge domain knowledge and decision support with situational awareness presentations. Please see Figure 5. Decision and task models, knowledge of the information environment of the application domain, including concepts, events, and operations, are tightly-coupled with the human/machine interface and the visualization architecture in

order to produce timely, decision-centered visualizations. DCV uses knowledge to track the context of an evolving situation, to classify and prioritize incoming operational data, and to automatically tailor and organize presentations in context with the tasks and decisions being worked, enabling a genuine human/machine information symbiosis. The main objectives of DCV are to reduce the information workload of operators and decision makers by providing in-context, to-the-point information presentations, and to reduce decision time by timely presentation of mission-relevant and mission-critical information.

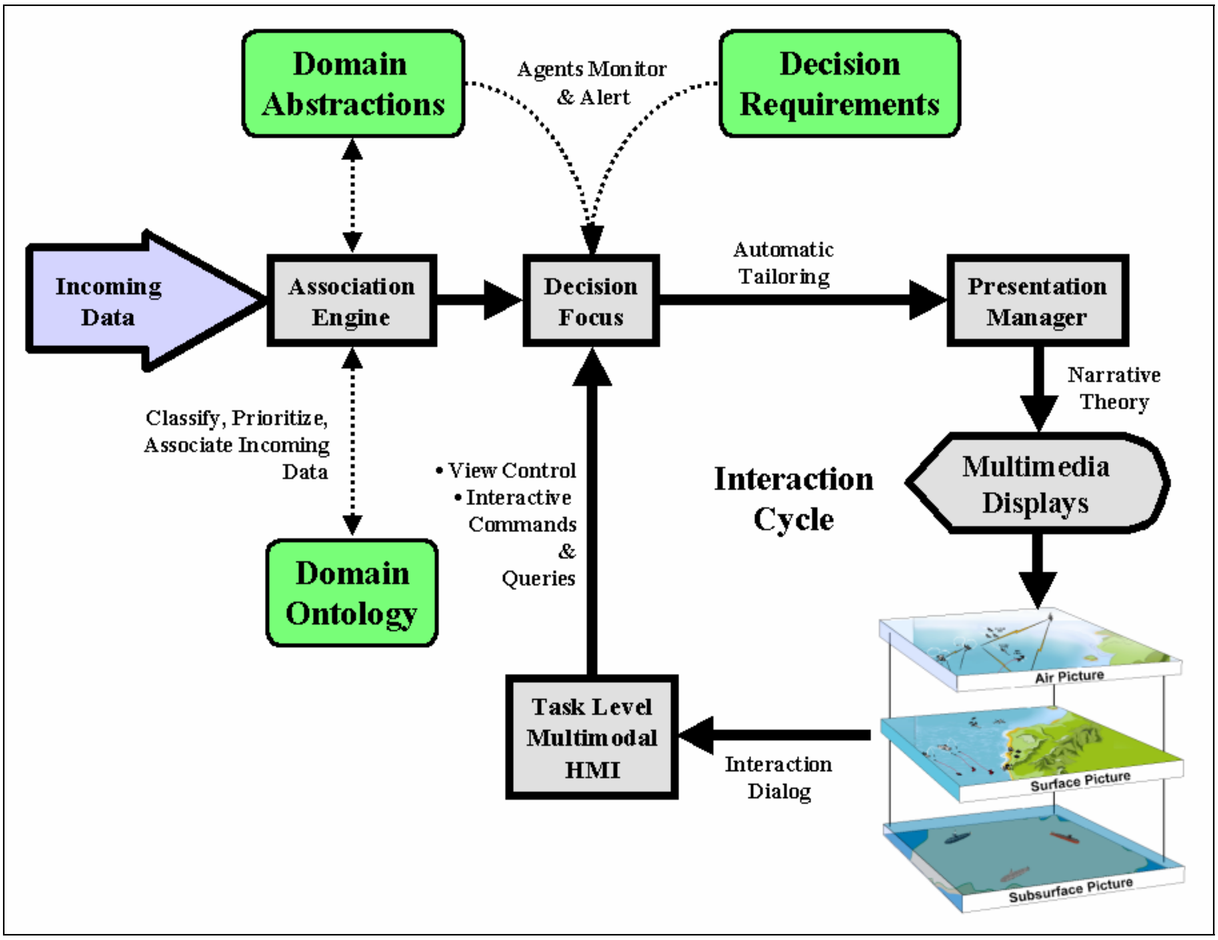

Figure 5: High-level Architecture for Decision-Centered Visualization (DCV). The distinguishing feature of this technology is the incorporation of knowledge modules into the visualization system. These knowledge modules consist of *domain ontology* and domain *abstractions, decision requirements* and *decision focus.*

The DCV architecture is intended to be domain-independent to support visualization in a variety of applications. Application-specific information is localized in well-defined modules – *domain ontology, domain abstractions*, and *decision requirements* – that are addressed early in the design phase when developing a particular application. The DCV *interaction cycle* is intended to be generic and parameterized in order to display and manipulate this application-specific information.

CONCLUSIONS AND FUTURE WORK

We have presented a variety of tools, approaches and paradigms in support of effective interactive data analysis for the underwater sonar space. Furthermore, Fraunhofer CRCG is currently investigating the

integration of knowledge engineering and visualization technology, to enable Decision-Centered Visualization

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[2] Encarnação, L.M., R.J. Barton, O. Bimber, D. Schmal-stieg (2000), *Walk-up VR: Virtual Reality beyond Projection Screens*. **IEEE Computer Graphics and Applications**, November/December 2000, pp. 19-23. IEEE Computer Society.

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[4] Schmalstieg, D., L.M. Encarnação, Zs. Szalavári (1999), *Using Transparent Props for Interaction with the Virtual Table*, **Proc. 1999 ACM Symposium on Interactive Three-Dimensional Graphics**, April 26-28, 1999, Atlanta, GA, pp. 147-154.

SYMPOSIA DISCUSSION – PAPER NO: 11

Author's Name(s):

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Mr. David Zeltzer, Fraunhofer Center for Research in Computer Graphics Inc., USA

Question:
How are the graphics displayed on the tablet?

Author's Response:
There are not any actual graphics on the tablet. The virtual reality environment can sense where the user is looking and can project the graphics to a location on the virtual table to make it seem like graphics are on the tablet.

Comment:
Experience can be incorporated in the development cycle when the rules are being implemented.

Question:
Has historical data been incorporated? Can the user ask for retrospective information?

Author's Response:
As this is a prototype, that has not yet been developed, however it would be important in an implementation of the system.

Large Scale Visualization Environment and Decision-Centered Visualization

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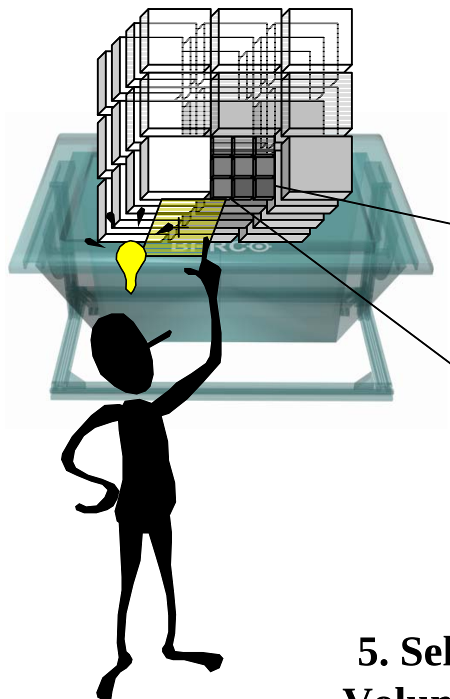
NEWPORT
Undersea Warfare Center Division

CRCG
Fraunhofer Center for Research in Computer Graphics Inc.

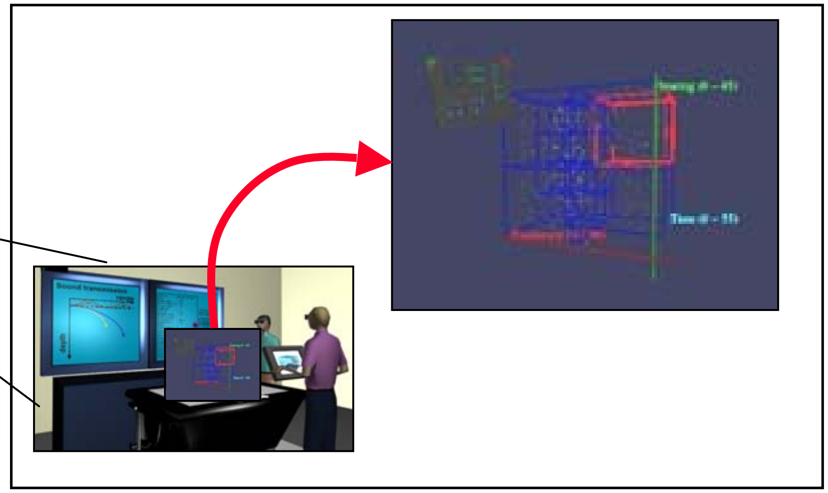
SONAR SDC Visualization

- Multi-Dimensional, Low Signal-to-Noise Data Space
  - Range, Bearing, Frequency,Time
- Many Sensors ➔ Data Overload
- Since End of Cold War, Naval Operations inVery Noisy Littoral Waters
- Is There a Better Way to Visualize SONAR Data?

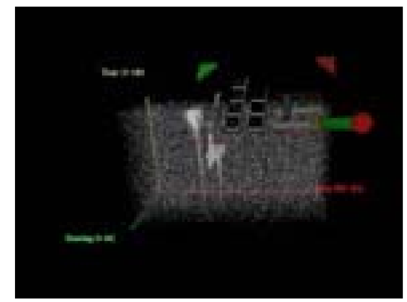
1. Rapid Scan for Volumes of Interest



2. Select Volumes of Interest for Abstract Broadband Visualization

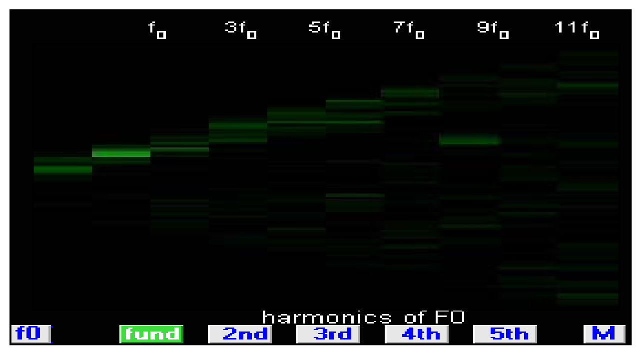


3. Multimodal and Multimedia for Detailed Analysis of Abstract Data



4. Apply Visualization Tools & "Grams" to Examine Actual Data

GIST Harmonogram



5. Select Another Volume of Interest

LSVE USW Visualization

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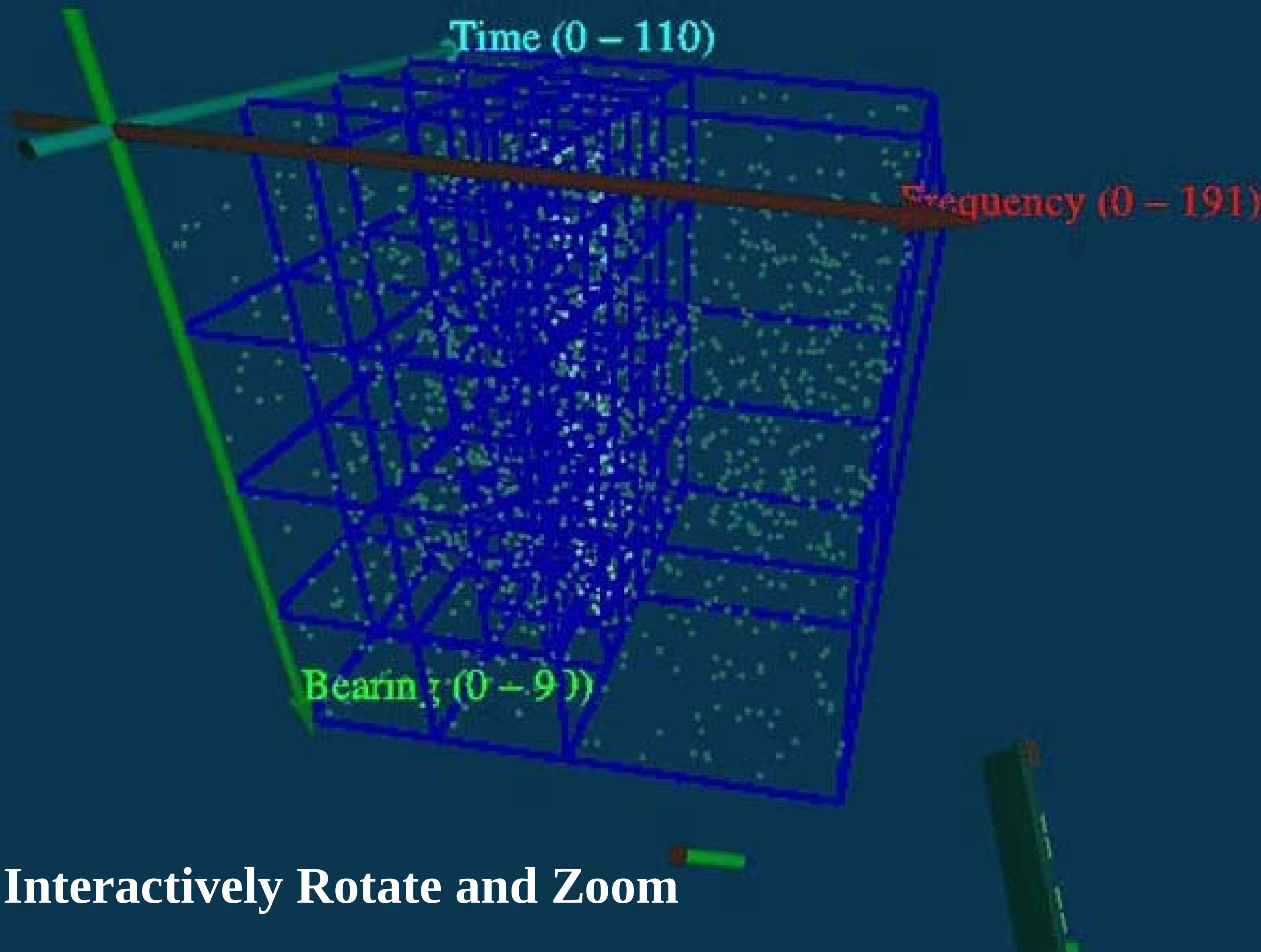
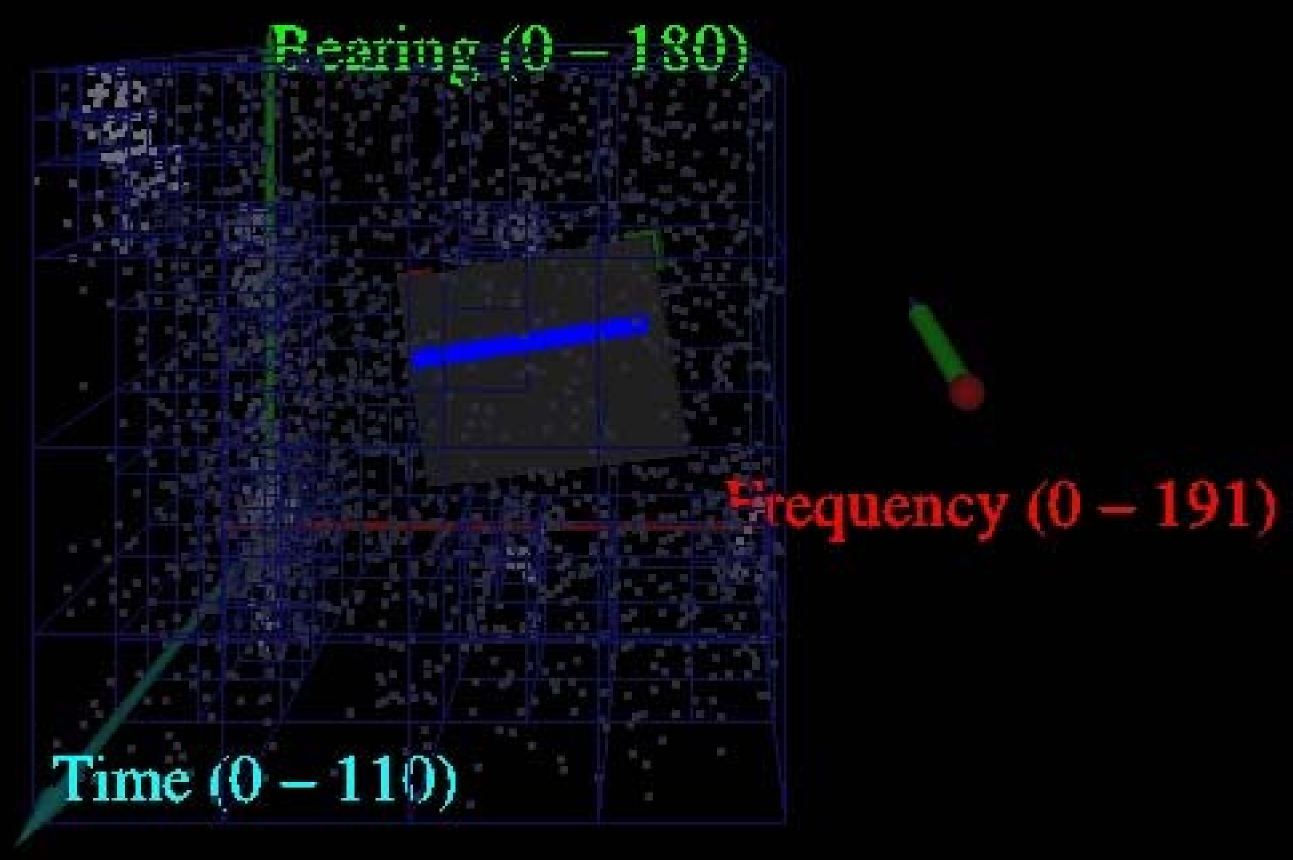
Visualize Volume of Interest

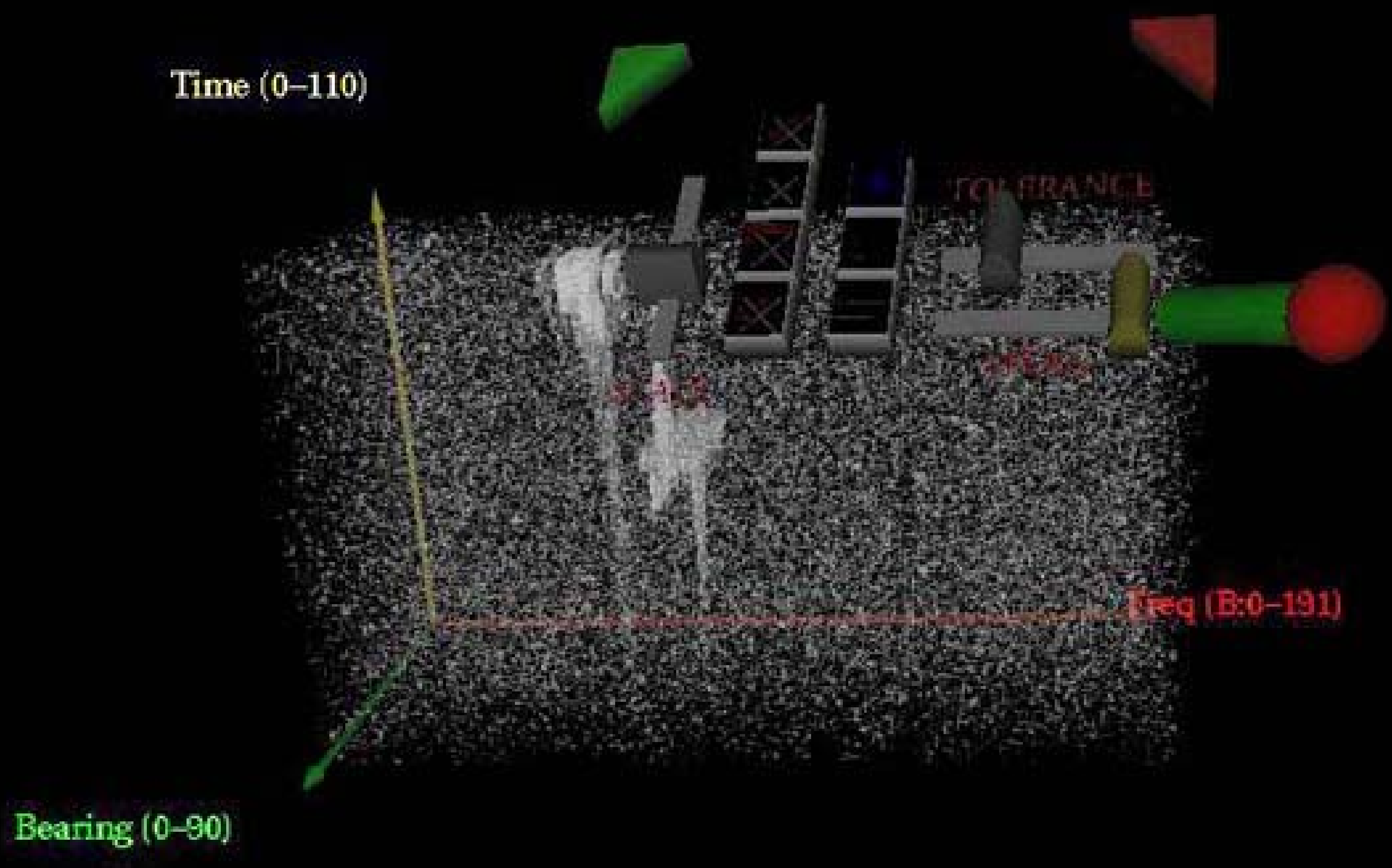


Interactively Rotate and Zoom

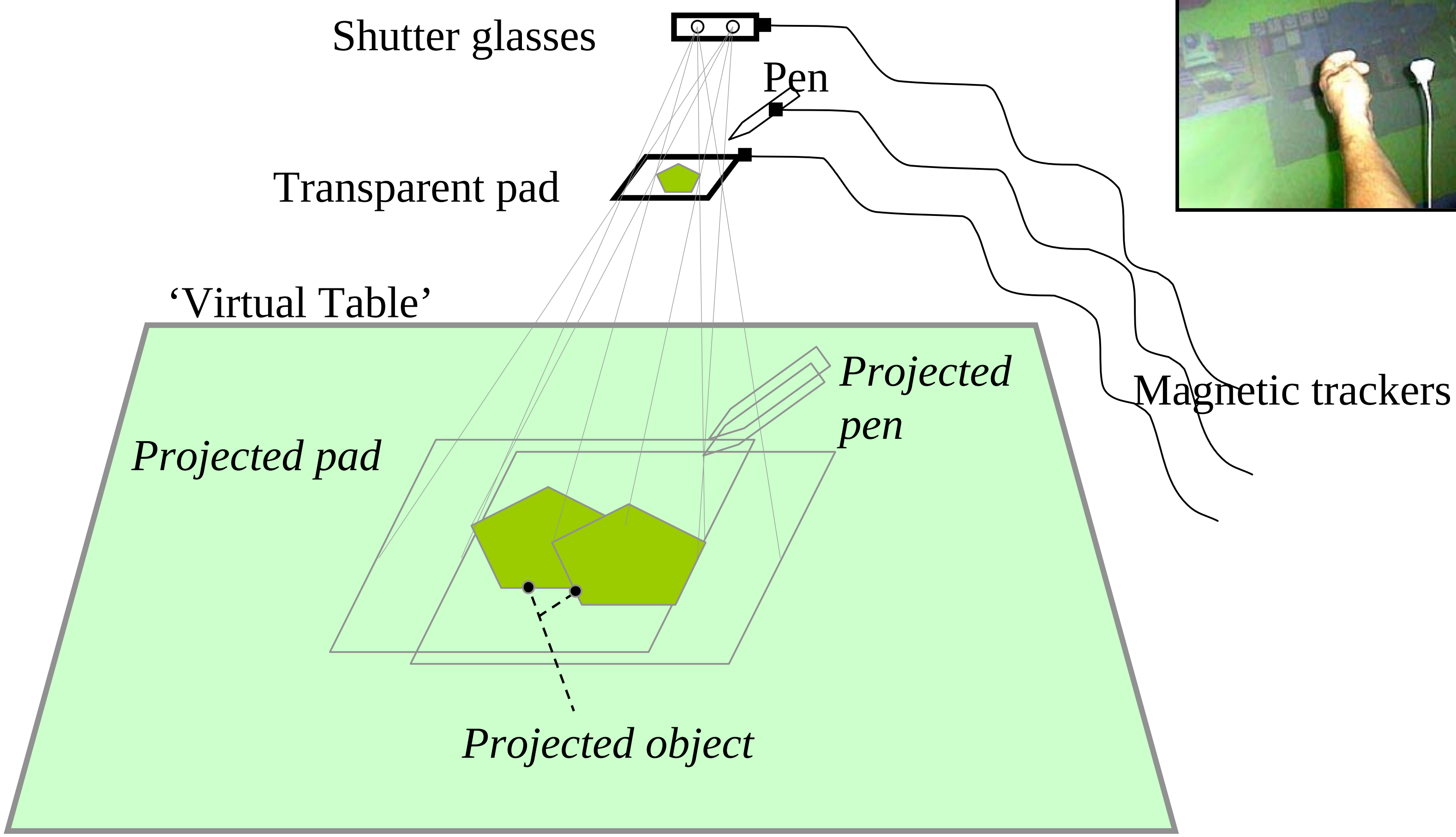
Spatially Probe with Sonification

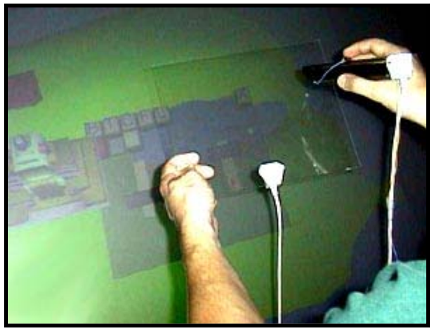


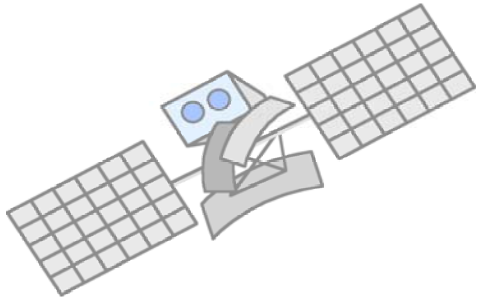
Interactively View and Manipulate Actual Data

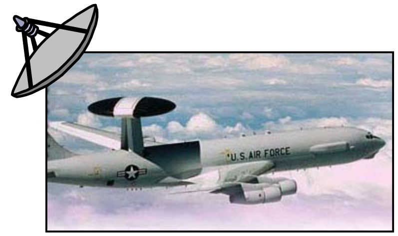


3D Interaction Technology
Virtual Table



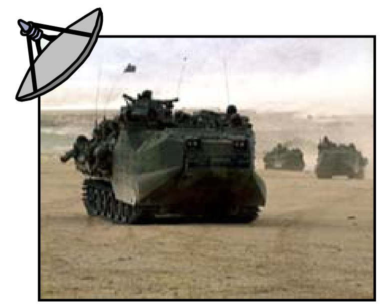


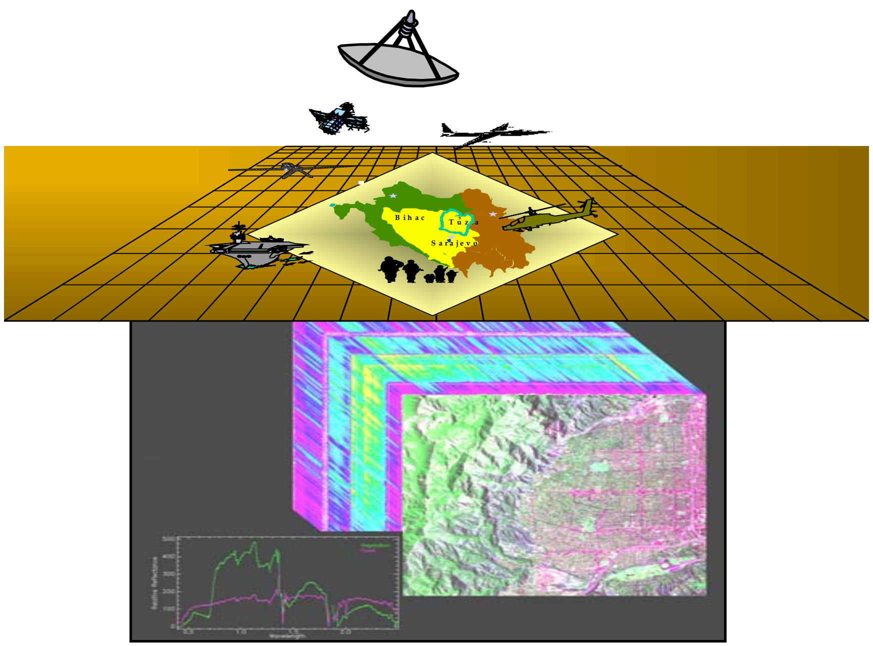




Decision-Centered Visualization

Fraunhofer Center for Research in Computer Graphics





Background

- Environmental Complexity, Fog of War
  - Littoral environments – sea, land, air
  - Friendly, hostile & neutral forces; air/surface/water craft
- Operational Restrictions – ROE
- Speed of Change
  - High speed weapons
  - Rapid, coordinated force deployment
- High Volume Data from Multiple Sources and Sensors
- Result — Information Overload!

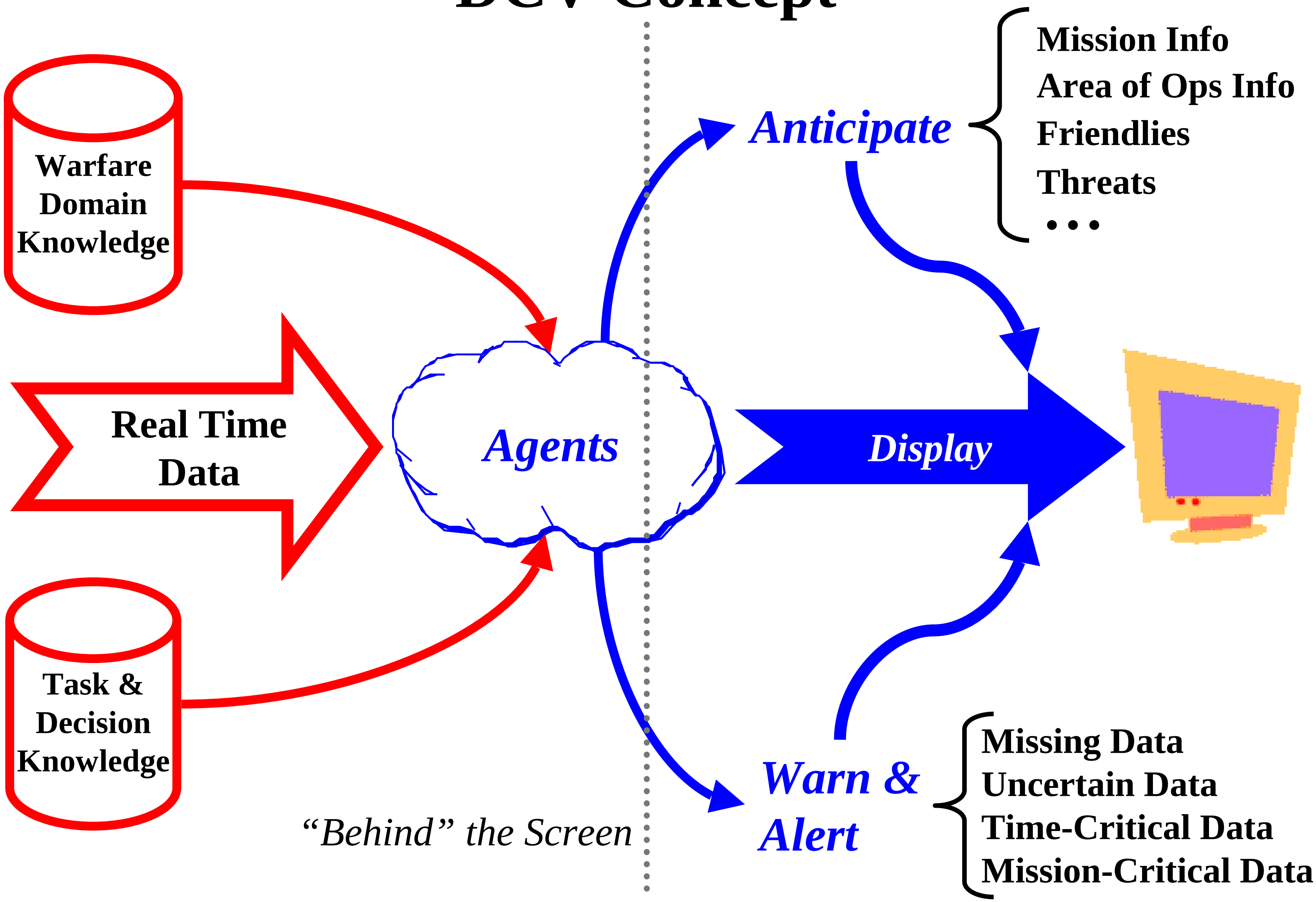
Take-Away Message

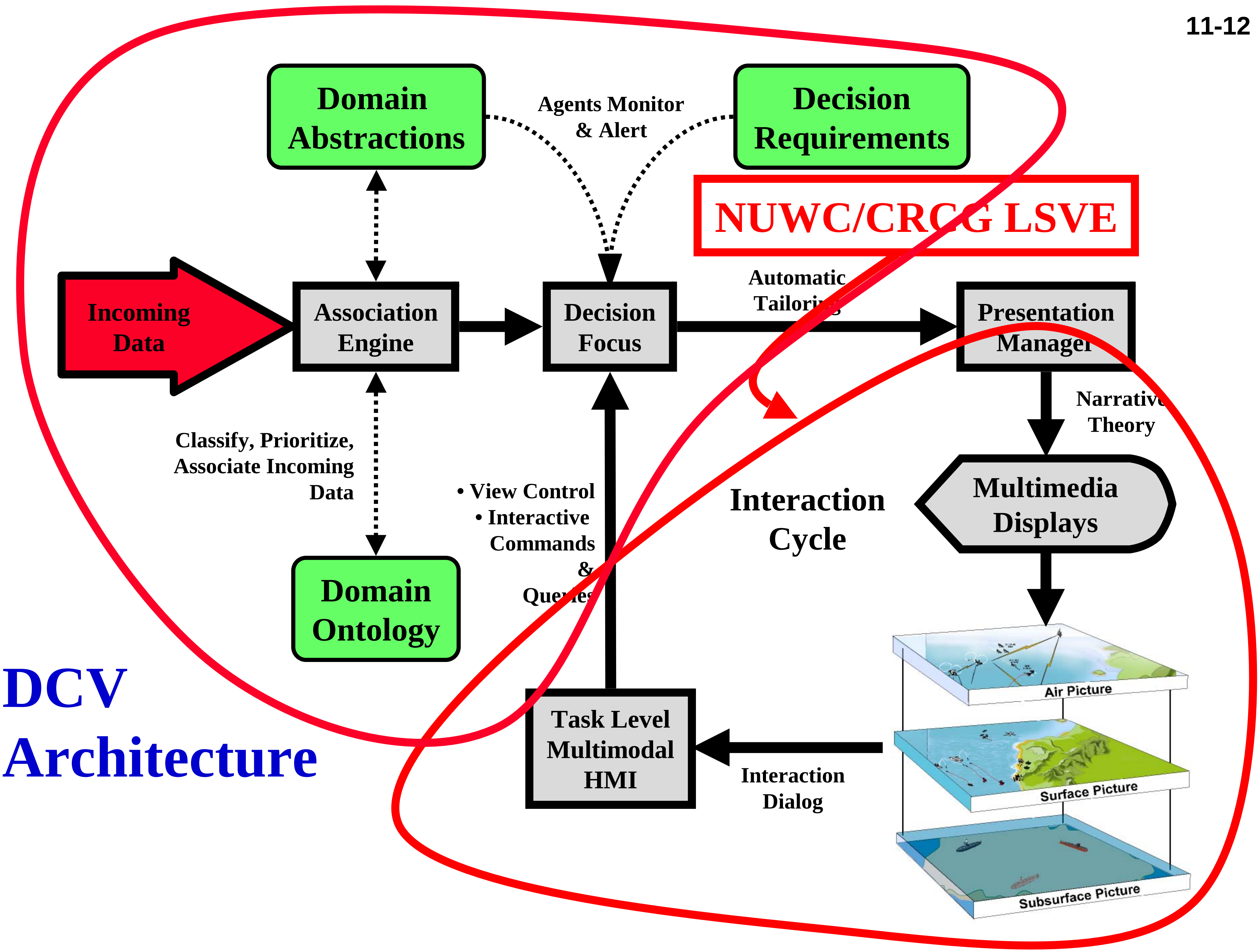
Information Overload?

Can’t Just Push More Pixels at People

Use Agents and Knowledge to
- ***Anticipate* What People Need to Know**
- **Build Integrated, Intuitive Displays**

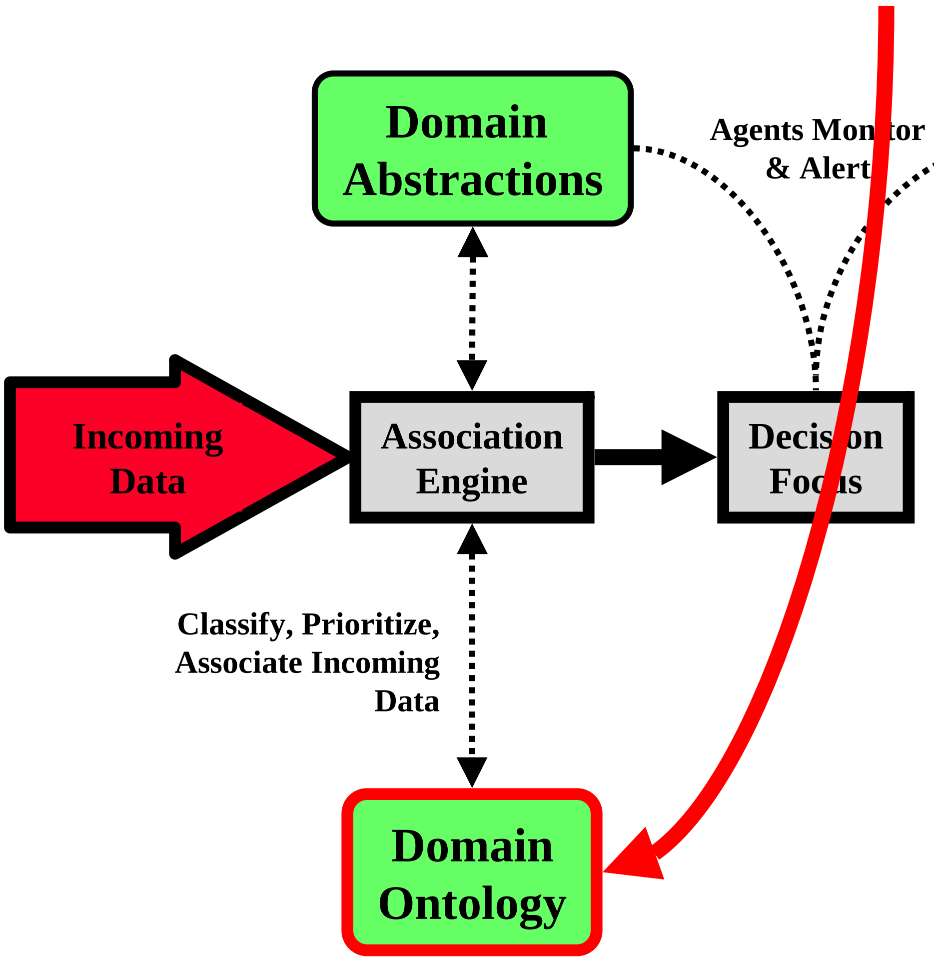
DCV Concept


Warfare
Domain
Knowledge
Real Time
Data
Task &
Decision
Knowledge
Agents
"Behind" the Screen
Anticipate
Mission Info
Area of Ops Info
Friendlies
Threats
• • •
Display
Warn &
Alert
Missing Data
Uncertain Data
Time-Critical Data
Mission-Critical Data



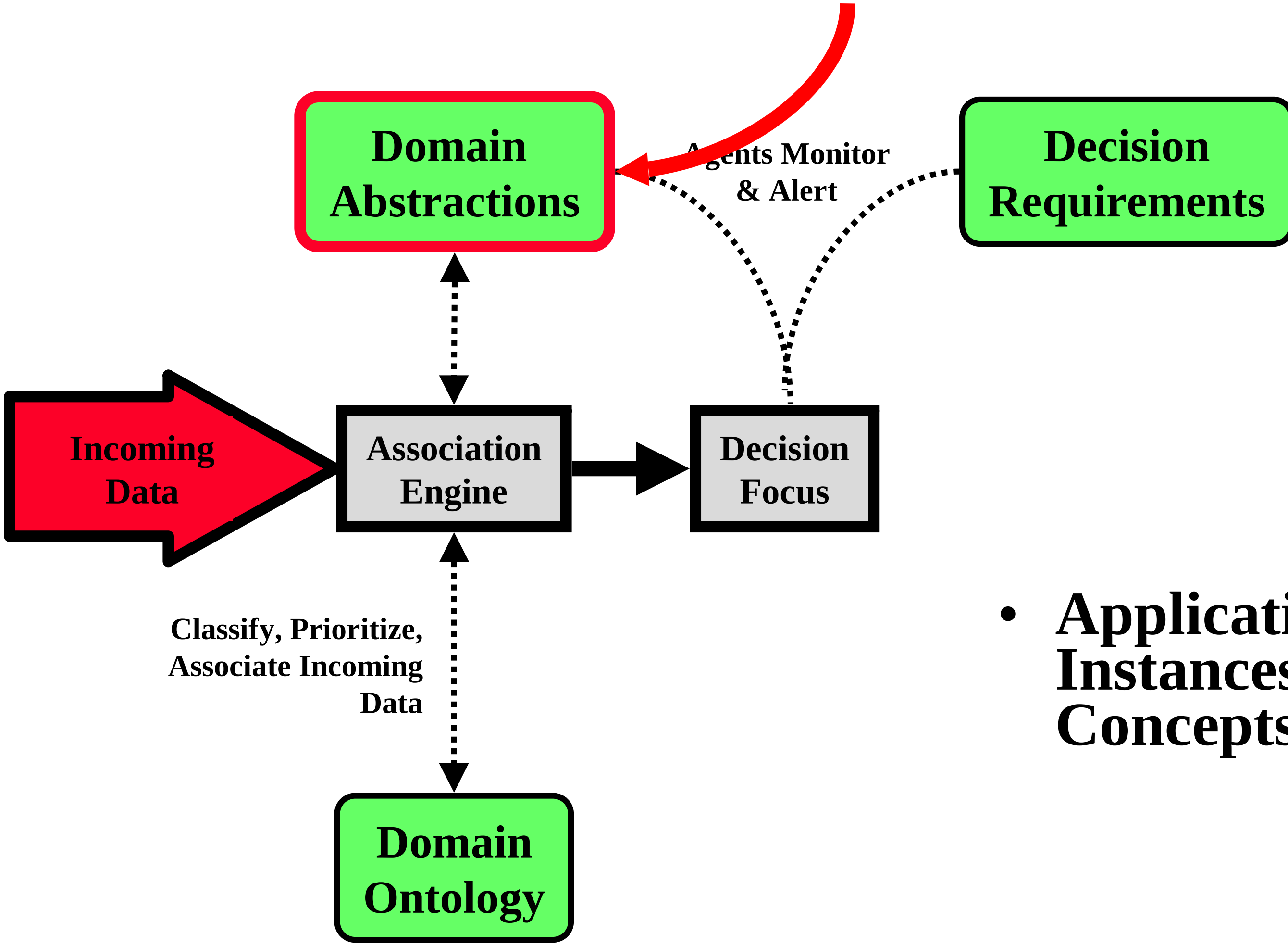
DCV Architecture

Warfare Domain Ontology



- **What Are the *Things* and *Actions* in the World?**
- **How Do They Relate to Each Other?**

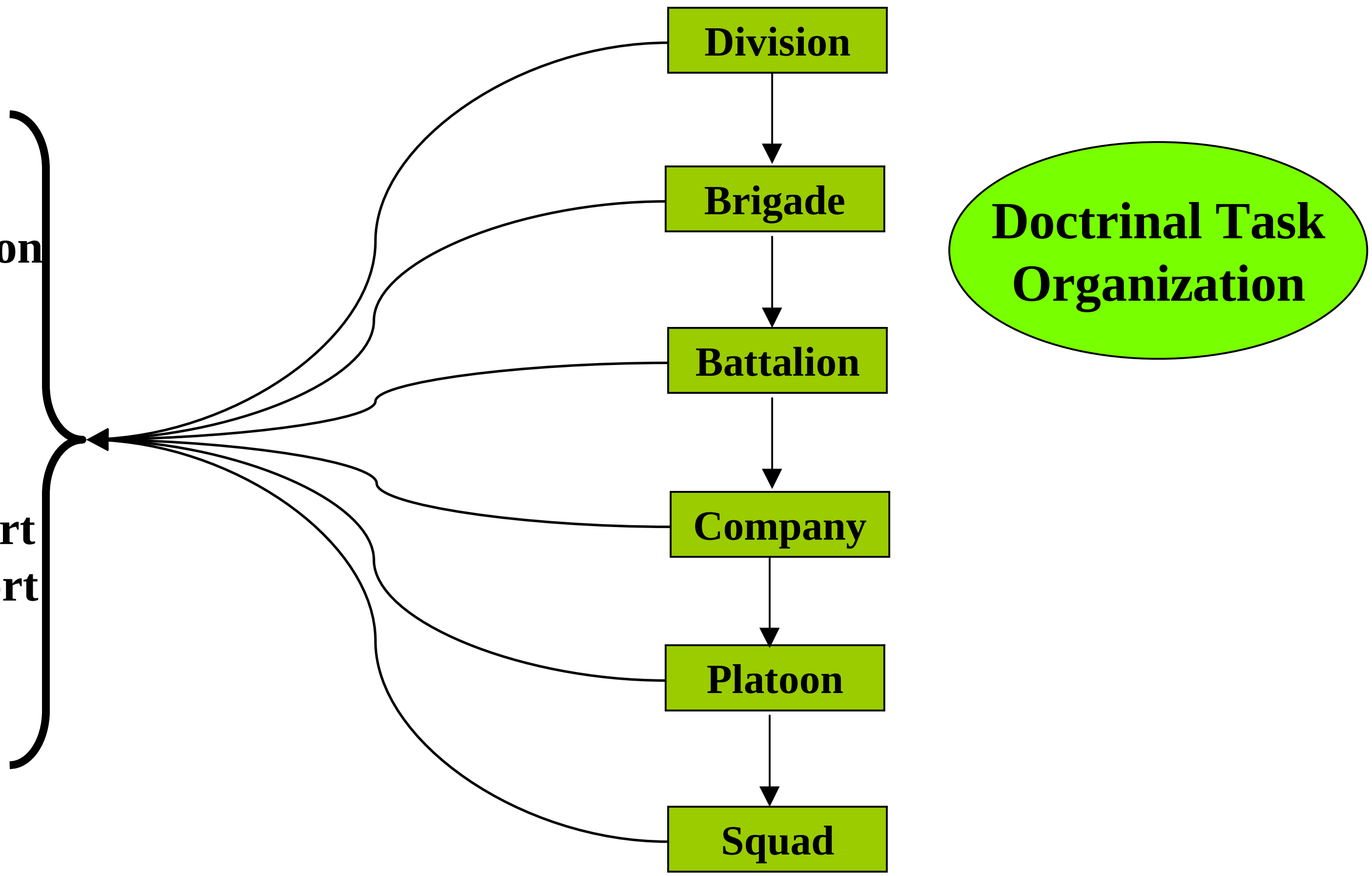
Domain Abstractions



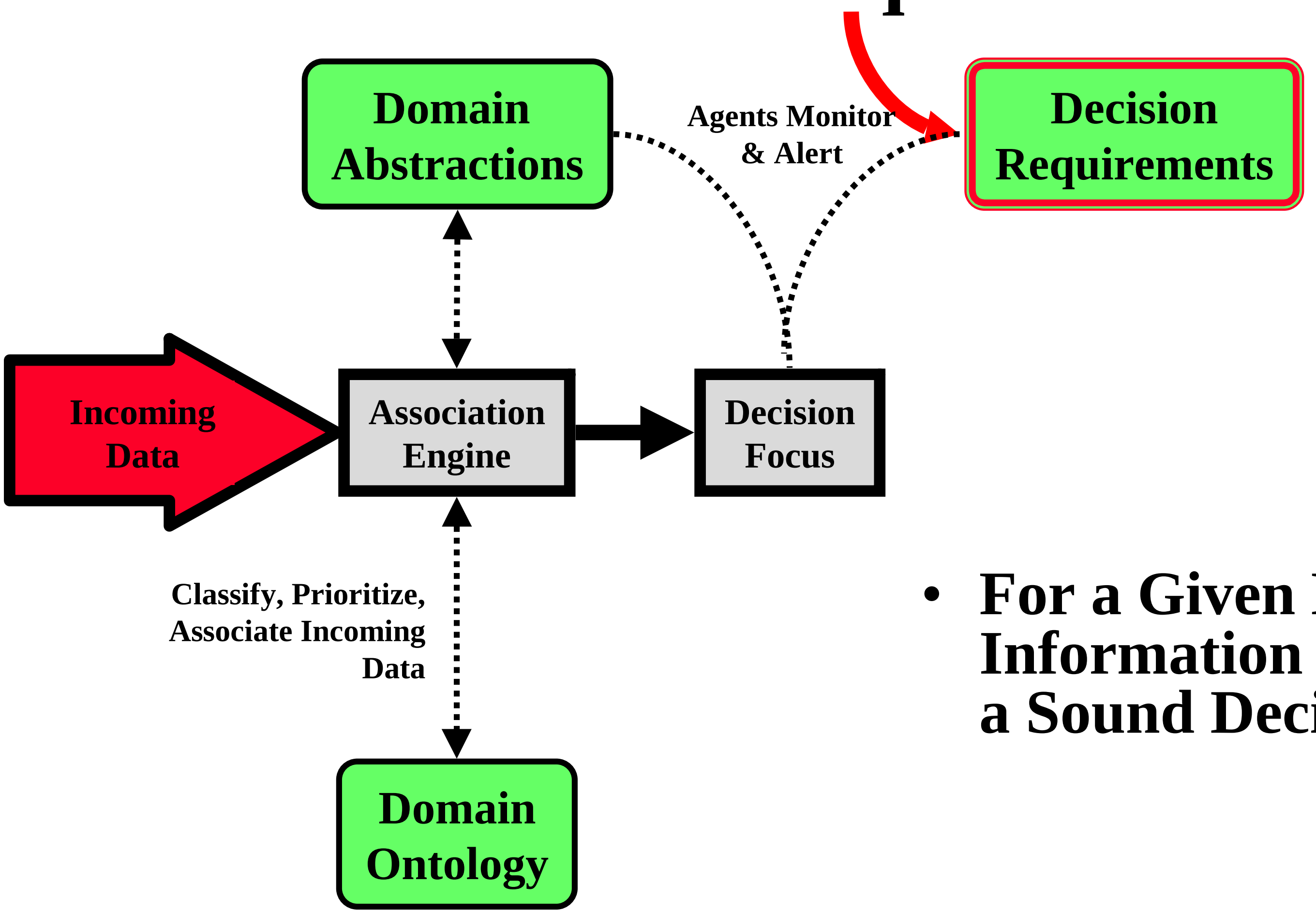
- **Application-Specific Instances of Ontology Concepts**

Infantry SA Domain Abstractions

- Unit type
- Home base
- Current location
- Readiness
- Resources
- Capabilities
- Strength
- Logistic support
- Combat support
- Weapons
- Equipment
- . . . . . .



Decision Requirements



- **For a Given Decision, Information Needed to Make a Sound Decision**

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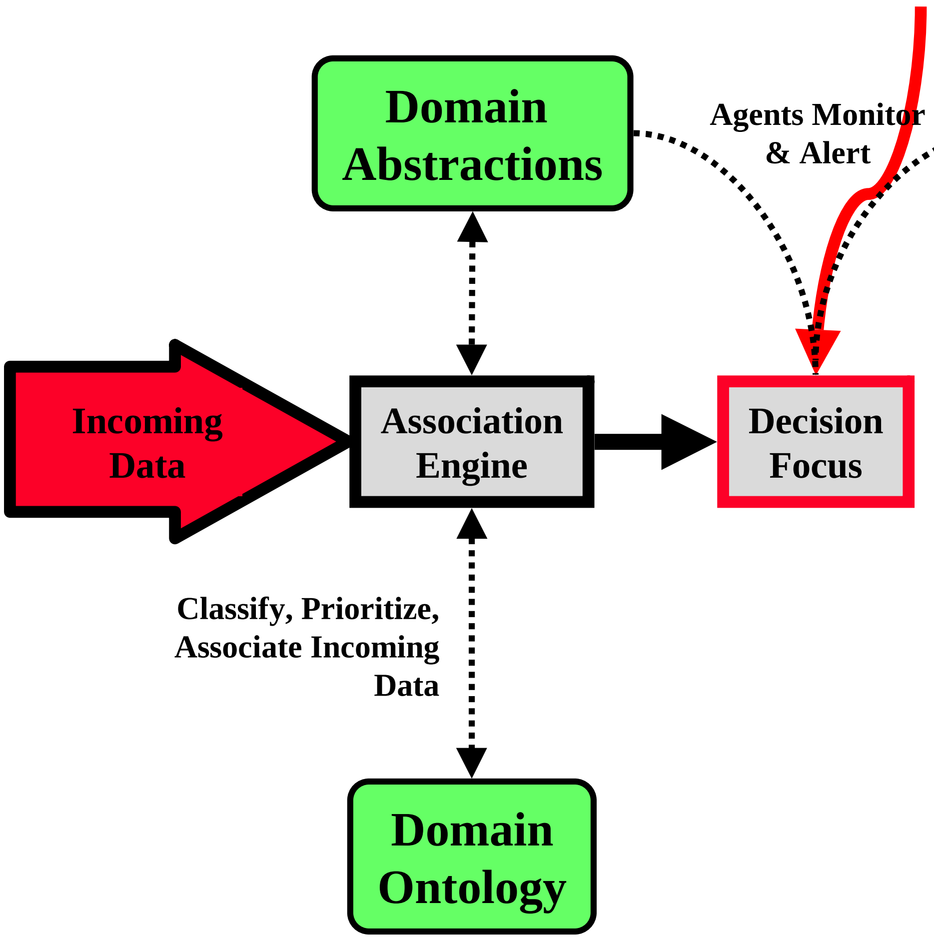
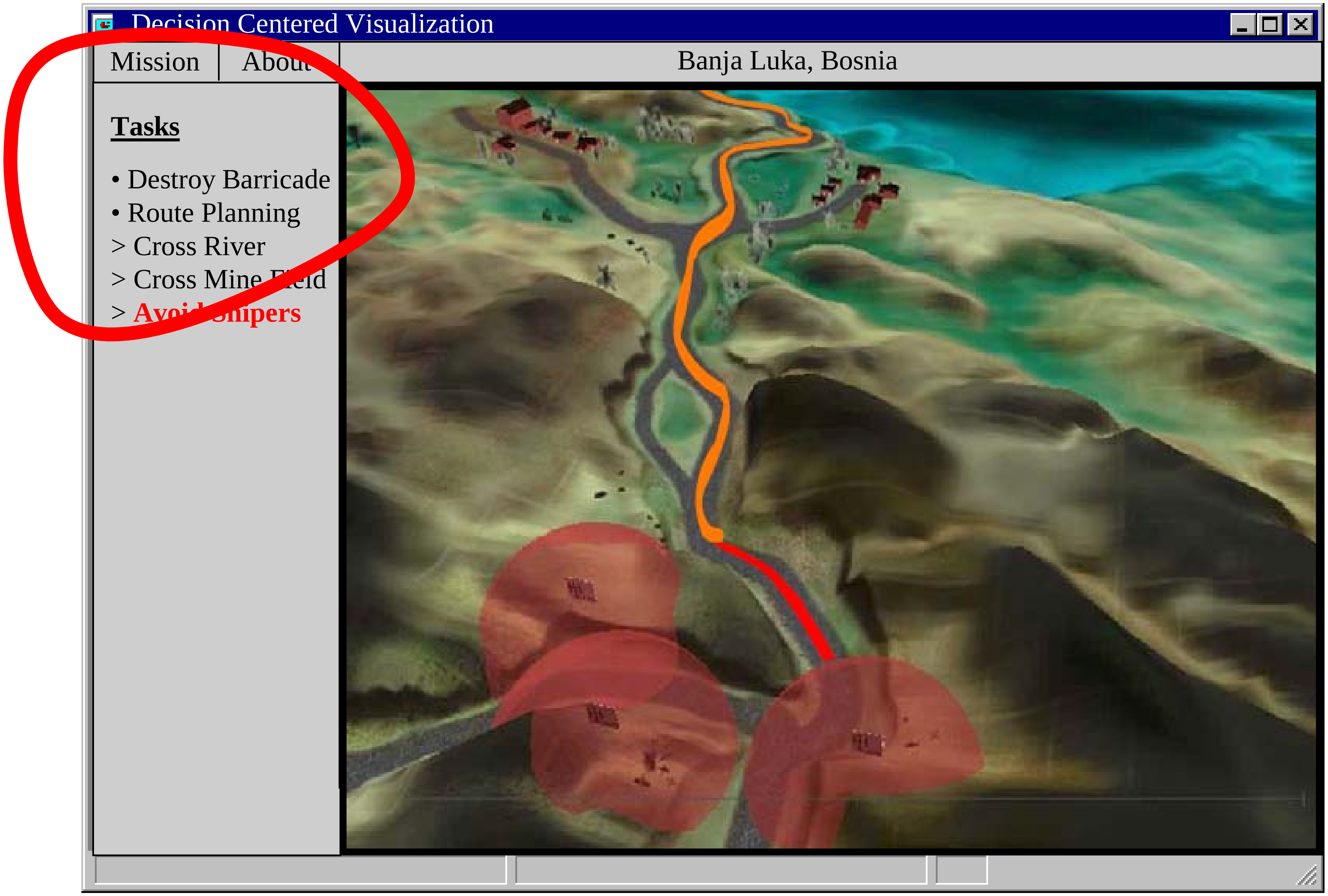
Decision Focus



Computer Inference of Intentions from Behavior Remains "Grand Challenge"

For DCV, Decision Maker Explicitly Specifies Current Mission Event(s),Task(s) & Decision(s)

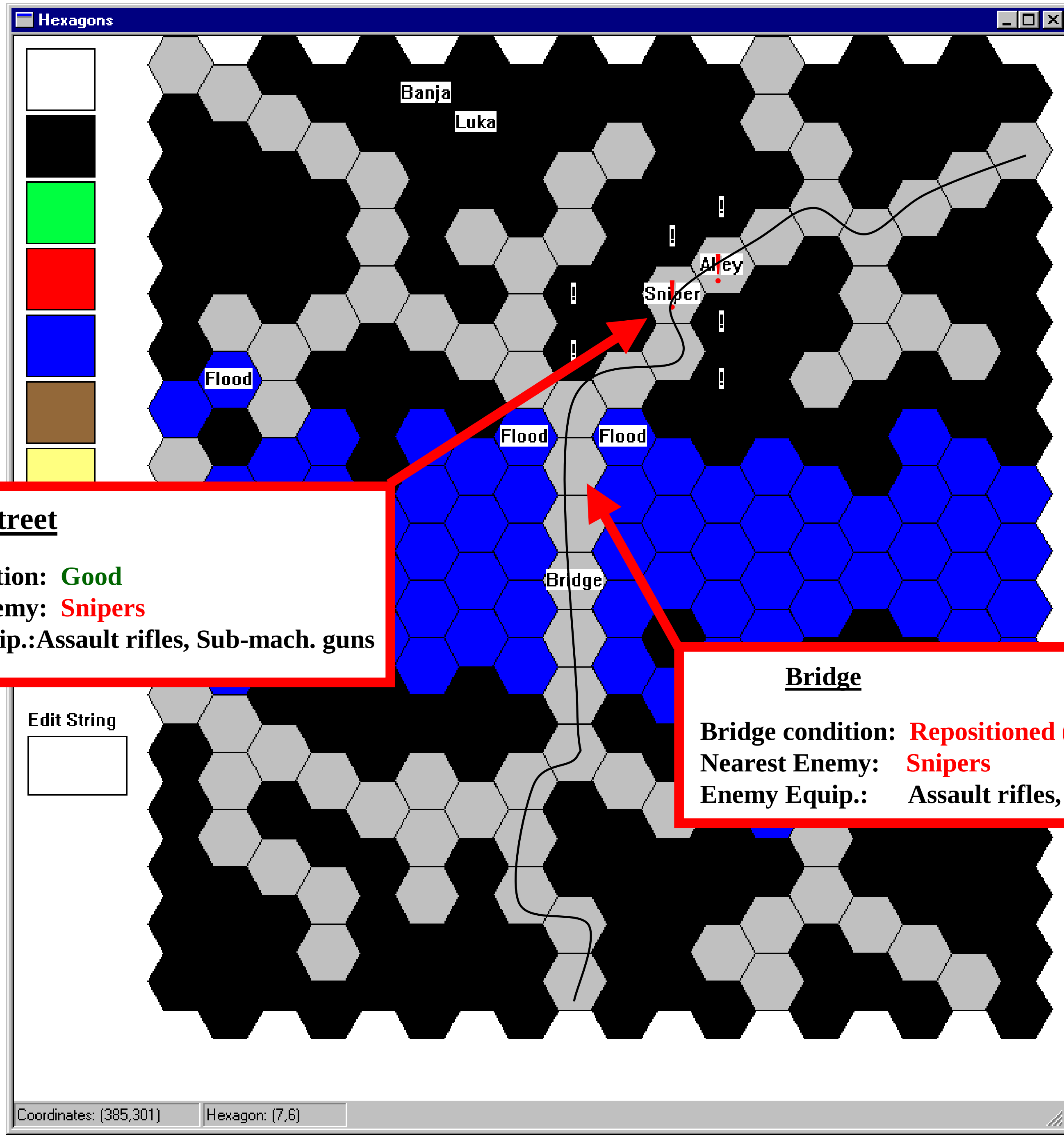
Prototype Decision Focus GUI



NAVSEA NEWPORT Undersea Warfare Center Division

Fraunhofer CRCG Center for Research in Computer Graphics Inc.

- Human Proposes Route
- DCV Suggests & Alerts



“Smart Maps” for Infantry SA

- Information Push/Pull

Thank You!